

BIENNIAL VARIATION IN SPRINGTIME TEMPERATURE AND TOTAL OZONE IN EXTRATROPICAL LATITUDES

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ABSTRACT

During the past decade in extratropical latitudes, springtime stratospheric temperatures tended to be relatively high during the even years and relatively low during the odd years, with some evidence for a phase reversal in the troposphere. In the Southern Hemisphere this even-year stratospheric temperature excess appears to have progressed poleward with time, with the maximum excess occurring near the Tropic of Capricorn in 1955 and near the Antarctic Circle in 1965, where the excess averaged 8°C. even at 100 mb.

Total ozone measurements in both hemispheres tend to confirm such a poleward trend. Furthermore, in agreement with a period of order 20 yr. implied by the stratospheric temperature differences, the difference between (springtime) even-year and odd-year total ozone amounts at Arosa, Switzerland, exhibits about a 20-yr. periodicity from 1928 to 1966, with the ozone amounts averaging 10 percent higher during the spring of the even years around 1960.

Springtime surface temperatures in Scandinavia have undergone a similar (15- to 20-yr.) periodicity since 1850, with odd-year temperature excesses averaging 2°C. around 1959. After 1920, European stations exhibit like variations, but there is little evidence for such surface-temperature fluctuations in North America or in the tropical and temperate latitudes of the Southern Hemisphere.

It is suggested that there is an association between the cycling interval of the quasi-biennial tropical oscillation and the above fluctuations of period of order of 20 yr.

1. INTRODUCTION

In recent years, spring temperatures in the temperate-latitude stratosphere have tended to be relatively high during even-numbered years and relatively low during odd-numbered years. For example, figure 1 shows that at Invercargill, New Zealand (46°S.), at 50 mb. (about 20 km.); this tendency for August–September–October temperatures to be relatively high has existed since 1957, with the alternation particularly pronounced around 1960. During the fall months, however, there has been no systematic alternation whatsoever. Similarly, at Wakkanai, Japan (45°N.), 50-mb. spring (February–March–April) temperatures have been relatively high during the even years between 1953 and 1964, with some evidence that the alternation is now either reversing or breaking down and that a similar breakdown or reversal occurred prior to 1953. The Wakkanai temperature alternation is in accord with the results of Wallace and Newell [1], who found that the poleward flux of heat in the Northern Hemisphere stratosphere was greater during the winters of 1959–60 and 1961–62 than during the winters of 1958–59 and 1960–61. The interesting tendency for midwinter stratospheric warming to take place over Europe during the even years from 1958 to 1964 (Labitzke [2]) also may be associated with this springtime temperature alternation.

As a result of the well-known quasi-biennial temperature cycle in the tropical stratosphere, the 50-mb. Canton (3°S.) temperatures exhibit a somewhat similar variation (fig. 1), and it is reasonable to assume that these temperate and tropical-latitude alternations are in some way associated, without implying a cause and effect relationship. The association may not be simple, however, as in February–March–April the Canton fluctuations tend to be in phase with the Wakkanai fluctuations (after 1955),

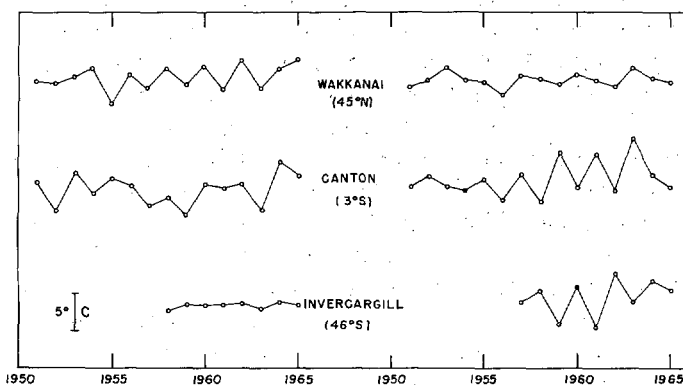


FIGURE 1.—Mean 50-mb. temperature during February–March–April (left) and August–September–October (right) for equatorial and temperate latitude stations. Temperature scale given in lower left.

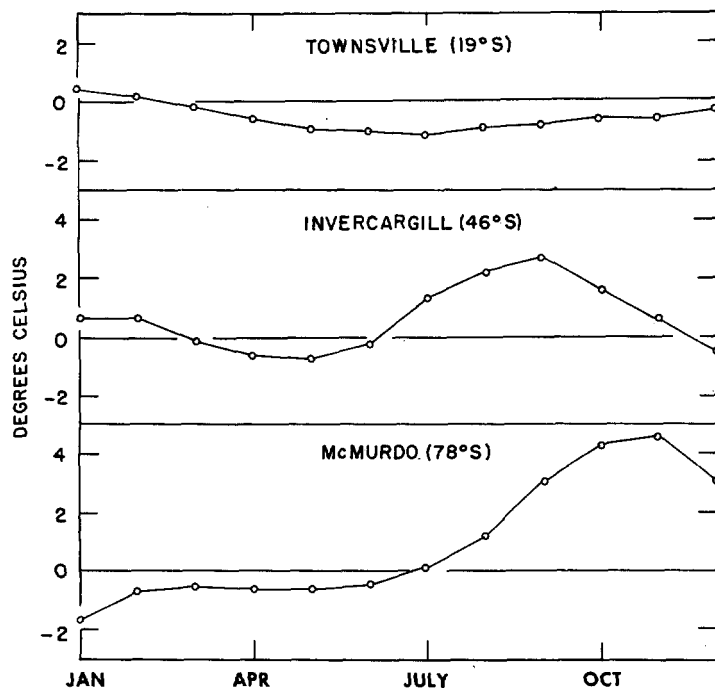


FIGURE 2.—Based on the period 1956–1965, even-year 100-mb. temperature minus odd-year 100-mb. temperature as a function of month for stations in tropical, temperate, and polar latitudes.

whereas in August–September–October the Canton fluctuations tend to be out of phase with the Invercargill fluctuations.

The purpose of this paper is to present a preliminary analysis of these yearly alternations in meteorological parameters in extratropical latitudes and to relate them to the quasi-biennial oscillation of tropical latitudes.

2. BIENNIAL FLUCTUATION IN STRATOSPHERIC TEMPERATURE

In order to pinpoint the months when the year-to-year alternation in stratospheric temperature is most pronounced, the 100-mb. (about 16-km). temperature difference between even and odd years was evaluated for the 10-yr. period 1956–1965 for Southern Hemisphere stations in tropical, temperate, and polar latitudes. Figure 2 shows that at Townsville, Australia (19°S.), the maximum (negative) difference occurs in July, at Invercargill (46°S.) in September, and at McMurdo, Antarctica (78°S.), in November. Thus, in the case of temperature (and total ozone as well) there is evidence that the maximum year-to-year variation occurs later in the spring as one progresses poleward. In the following this tendency has been taken into account, albeit in a conservative way, by letting “spring” represent the months of July–August–September in tropical latitudes, August–September–October in temperate latitudes and September–October–November in polar latitudes of the Southern Hemisphere, and the corresponding seasonal months in the Northern Hemisphere. The use of such fixed “spring” months probably results in a conservative estimate of the year-to-year variability actually present.

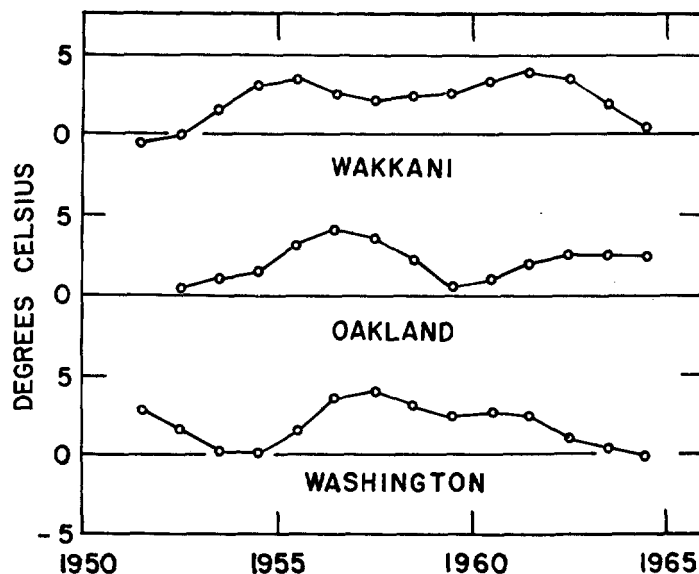


FIGURE 3.—Smoothed spring 50-mb. temperature excess, even-year minus odd-year, for temperate-latitude stations at different longitudes.

The analysis procedure utilized is as follows. A new series is formed as the sequence of first-differences of the original series of mean spring temperatures, with alternate signs of the difference reversed so as to yield a measure of the excess of even-year temperatures over odd-year temperatures. These differences are then smoothed by use of a 3-yr. running mean. Figure 3 shows how the 50-mb. Wakkani (45°N.) temperature data for February–March–April look when treated in this way. During the interval 1954–64, the even-year temperatures averaged about $2\frac{1}{2}^{\circ}\text{C}$. higher than the odd-year temperatures, with the difference a maximum in 1955–56 and 1961–62. Records of similar length are available for Oakland, Calif. (38°N.), and Washington, D.C. (39°N.), and are shown in figure 3. These stations also exhibit a tendency during this period for the spring temperatures of even years to exceed the spring temperatures of odd years. Thus, the phenomenon appears to be hemisphere wide, even though there are subtle longitudinal differences.

A quasi-meridional section, situated for the most part in the western Pacific, was utilized to depict the latitudinal variations of the yearly temperature alternation (fig. 4). This particular section was chosen because of the length of record of the stations that comprised it, and because the yearly alternation appears especially pronounced this region [3]. To extend the length of record in the Southern Hemisphere, with the exception of Canton, 100-mb. temperatures were used. The right diagram of figure 4 shows the smoothed, Southern Hemisphere spring temperature difference, even year minus odd year, as a function of latitude and year. Even at the relatively high pressure of 100 mb., the excess of even-year tempera-

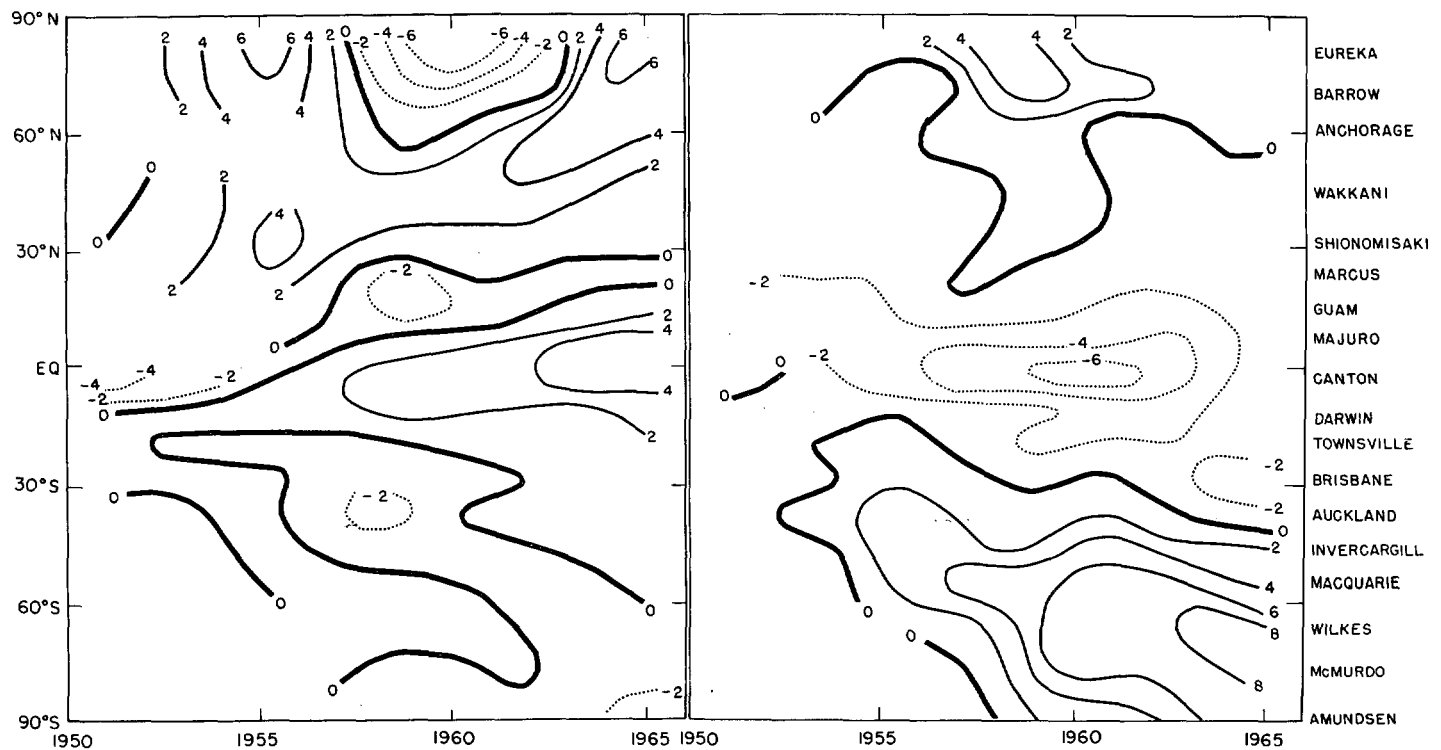


FIGURE 4.—On the basis of 50-mb. temperatures in the Northern Hemisphere and 100-mb. temperatures in the Southern Hemisphere, the temperature excess of even years with respect to odd years (solid lines) and odd years with respect to even years (dashed lines) for the Northern Hemisphere spring (left) and the Southern Hemisphere spring (right). Temperatures in degrees Celsius; stations utilized indicated along margin.

tures over odd-year temperatures is very pronounced in the Southern Hemisphere, attaining a value of 8°C . in the Antarctic by 1965. According to data presented by Rubin and Weyant [4], this large alternation in the Antarctic is closely connected with the date and intensity of the stratospheric spring warming, a much more regular phenomenon in the Antarctic than in the Arctic.

Of considerable interest is the evidence for a poleward trend with time of the even-year temperature excess, with the peak excess occurring near the Tropic of Capricorn in 1955 and near the Antarctic Circle in 1965. There is the suggestion that this extratropical excess originated in the excess of (July–August–September) even-year temperatures over odd-year temperatures which must have occurred in the lower tropical stratosphere prior to 1950. Accordingly, the progression time from Equator to pole of the excess-temperature wave is estimated at about 20 yr. As the result of such a phenomenon, a station at any particular latitude would experience a nearly 20-yr. periodicity in even-odd year temperature difference. Note that, viewed in this light, the disappearance of the biennial variation in stratospheric temperature and total ozone at Australian and New Zealand stations in 1964, as reported by Sparrow [5] and Kulkarni [6], is simply a result of the poleward progression of the phenomenon.

In the Northern Hemisphere spring the situation is not so clear cut (left diagram of fig. 4). Also here a poleward progression of an even-year temperature excess is evident, but it is not as pronounced as in the Southern Hemisphere and is masked by erratic fluctuations in polar latitudes. The latter might be expected owing to the complicated nature of the circulation patterns in the Arctic in comparison with the Antarctic. There are also complexities in the Tropics related to the fact that, during the spring, equatorial and temperate-latitude stations are in phase (even years warm, odd years cold) rather than out of phase, as in the case of the Southern Hemisphere spring. Whether this implies a real asymmetry between hemispheres or is merely a consequence of the phase-relation between the tropical quasi-biennial oscillation and month of the year is uncertain. Finally, in the Southern Hemisphere fall there is a poleward progression of temperature excess in odd years relative to even years so that, at least in this Hemisphere, the fall months tend to act in a sense opposite to that of the spring months.

3. BIENNIAL FLUCTUATION IN TOTAL OZONE

Prior to 1950, stratospheric temperature data are sparse, and it is not feasible to utilize such data to backtrack further in time. There is a good correlation, however,

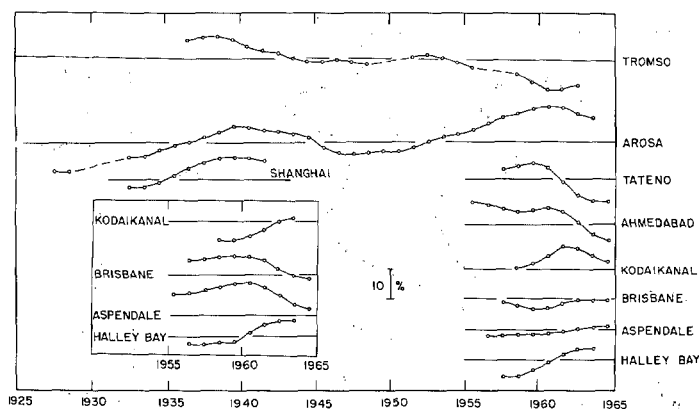


FIGURE 5.—Total ozone difference, even-year minus odd-year, during Northern Hemisphere spring and, in inset, during Southern Hemisphere spring. Difference expressed as percent of spring average total ozone amount at the various stations (scale in middle of diagram).

between temperatures in the lower stratosphere and total ozone amounts [7], so that the relatively long total ozone record at stations such as Arosa, Switzerland (47°N.), can be used for this purpose. Figure 5 shows the difference between even-year and odd-year total ozone amount (expressed as a percentage of the average seasonal amount of total ozone) for a number of stations during the Northern Hemisphere spring and, in the inset, during the Southern Hemisphere spring. In conformity with the temperature observations, note the evidence for a poleward progression of the even-year total ozone excess during the Northern Hemisphere spring, with the excess the greatest prior to 1955–56 at Ahmedabad, India (26°N.), in 1959–60 at Tatenō, Japan (36°N.), and about 1961 at Arosa, Switzerland. A similar poleward progression is to be found during the Southern Hemisphere spring with the excess of even-year ozone over odd-year ozone a maximum during 1959–60 at Brisbane, Australia (28°S.), during 1960–61 at Aspendale, Australia (38°S.), and apparently about 1963 at Halley Bay, Antarctica (76°S.). Again in accord with the stratospheric temperature observations, during the fall months of the past decade, stations in tropical (Kodaikanal, India, 10°N.) and temperate latitudes generally have had lower total ozone values in even years than in odd years, as if the ozone content of the fall hemisphere was lowered due to the high ozone content of the spring hemisphere and conservation considerations.

Of particular interest in figure 5 is the ozone record for Arosa. A periodicity of approximately 20 yr. (19.5 yr. according to the correlogram) is clearly evident in this trace, with the total ozone excess in even years relative to odd years a maximum in 1940 and 1960 (the latter in agreement with stratospheric temperatures) and the excess in odd years relative to even years a maximum in 1948 and about 1928, although the data are sparse near the latter date. An early portion of the Arosa trace is highly corre-

lated with Shanghai, China (31°N.), total ozone data available from 1932 to 1942, suggesting that the even-year ozone excess around 1940 was hemisphere wide. Near 1960, the even-year total ozone amount averaged 10 percent higher than the odd-year amount. This is considerably more than was noted near 1940, and there appears to be a long-term trend which has resulted in relatively large ozone amounts in even years during the past decade at Arosa.

Even though many gaps exist in the total ozone data from Tromsø, Norway (70°N.), the even-odd year comparison is difficult to reconcile with that of Arosa. For example, just prior to 1940 the Tromsø trace is nearly in phase with the Arosa trace, whereas around 1960 the two traces are nearly out of phase (the Tromsø correlogram yields a periodicity of only 15 yr.). The latter out-of-phase relationship is in agreement with the stratospheric temperature results indicated in the left diagram of figure 4. There also appears to be an out-of-phase relationship in the long-term trend delineated by these two stations, i.e., at Tromsø during the past decade the spring total ozone amount has tended to be relatively high during the odd years.

4. BIENNIAL FLUCTUATION IN SURFACE TEMPERATURE

Meteorological data for the stratosphere are practically nonexistent prior to the initiation of total ozone observations, so that a further extension backward in time must rely upon surface data. Landsberg et al. [8] analyzed several long-term surface-temperature records in their study of the quasi-biennial oscillation, and one of these (Uppsala, Sweden) provided visual evidence of a biennial periodicity in surface temperature. Accordingly, three stations in Europe [Basel (48°), Geneva (46°), Vienna (48°)], Scandinavia [Bergen (60°), Oslo (60°), Uppsala (60°)], and North America [New Haven (41°), Montreal (45°), Toronto (44°)] with long periods of record were selected, and the average even-year minus odd-year difference in spring surface temperature was determined for each set. Figure 6 shows smoothed (3-yr. running mean) traces of these differences and, for comparison, the results for total ozone obtained at Arosa. From 1855 to the present, the Scandinavian trace undergoes quasi-periodic fluctuations of 15- to 20-yr. period. The European spring-time trace exhibits a higher frequency fluctuation up to about 1920, after which the trace becomes similar to that of Scandinavia. The correlation between the Scandinavian and European traces from 1875 to the present is 0.70, a highly significant value. On the other hand, the North American trace consists exclusively of higher frequency fluctuations and possesses no appreciable correlation with either the European or the Scandinavian trace.

Based on 30 yr. of (unsmoothed) simultaneous data, the above European surface-temperature data tend to be out of phase with the Arosa total ozone data, with a correlation between the two of -0.57 , significant at the

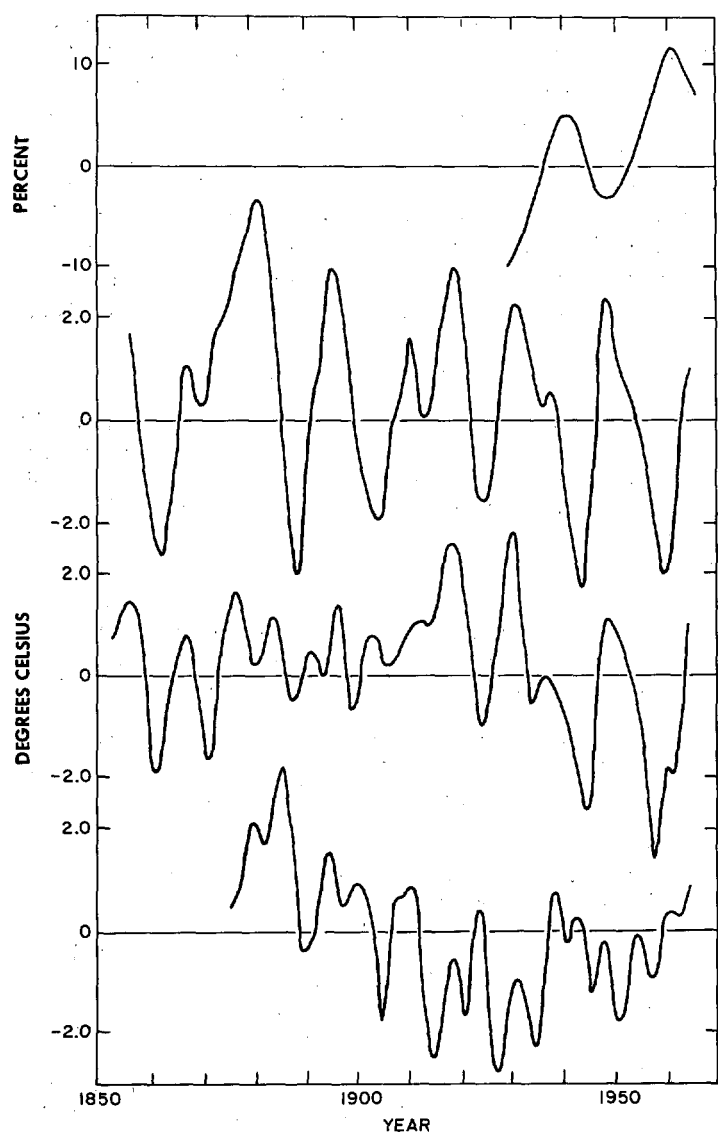


FIGURE 6.—Smoothed spring surface-temperature difference, even-year minus odd-year, at Scandinavian stations (top), European stations (middle), and North American stations (bottom). At the very top, for comparison, the Arosa total ozone trace has been copied from figure 5.

99 percent level according to Fisher's test. Such an out-of-phase relationship would be in accord with the phase relationship between stratosphere and troposphere at Invercargill (fig. 7), where a warmer-than-normal spring at 100 mb. was accompanied by a cooler-than-normal spring at 700 mb. However, since the even-year minus odd-year total ozone traces for Uppsala, Tromsø, and Lerwick, England (60°N.), exhibit differences, it may be unwise at this time to generalize concerning inverse correlations between the surface temperature and the temperature or total ozone content of the stratosphere.

To place things on a more analytic basis, correlograms (or serial correlations) based on unsmoothed, even-year minus odd-year data have been determined for the three

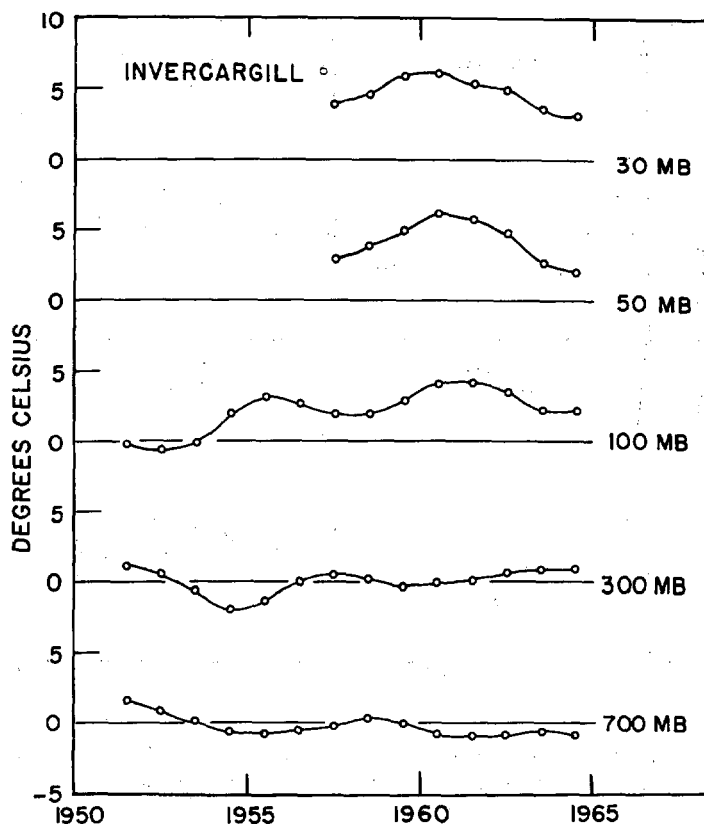


FIGURE 7.—Spring temperature difference, even-year minus odd-year, for various pressure surfaces at Invercargill, New Zealand.

sets of observations from 1875 to 1965 and also for the European data which exist between 1775 and 1875 (fig. 8). The Scandinavian correlogram is impressive and clearly peaks at a period of 17 yr. The early European correlogram suggests a basic periodicity of 9 yr., but the later one peaks at 12 yr. and 18 yr. Although the double peak in the latter case presumably reflects the difference in periodicity before and after 1920, there is the question what this difference in periodicity signifies. Note that the North American correlogram yields little evidence of periodic fluctuations.

In as much as the even-minus-odd year stratospheric temperature difference is at least as pronounced in the Southern Hemisphere as in the Northern Hemisphere, figure 7 suggests that it would be logical to search for a 15- to 20-yr. periodicity in surface temperature data in the Southern Hemisphere. Unfortunately, in that Hemisphere there are no available long-term surface-temperature records at latitudes similar to the Scandinavian latitudes, and the data at the more equatorward stations provide little support for such a periodicity. Consequently, unless some long-term temperature records can be obtained from stations south of Wellington, New Zealand (41°S.), it is not possible to state whether or not there is an asymmetry between hemispheres in this respect (perhaps due to the effect of continentality).

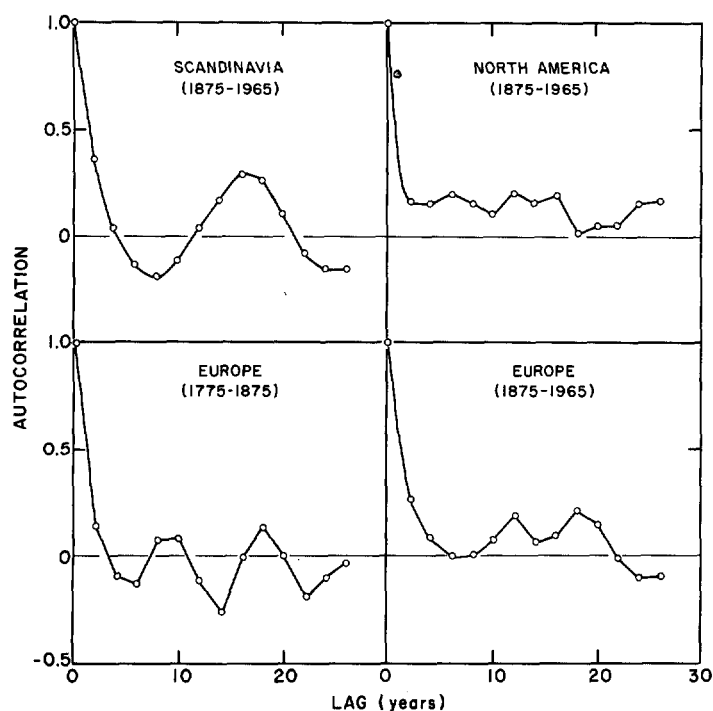


FIGURE 8.—Correlograms of even-year minus odd-year spring surface temperatures for various geographic regions and time intervals.

5. CONCLUSION

During the past decade the spring of the even years tended to be warmer (in the stratosphere) and to possess a greater amount of ozone than the spring of the odd years. Furthermore, in the Southern Hemisphere, evidence has been presented for a poleward progression of this even-year temperature excess, with the progression time from Equator to pole estimated at about 20 yr. Arosa total ozone data exhibit a nearly 20-yr. periodicity in even-minus odd-year values, while the Scandinavian stations have exhibited a somewhat similar 15- to 20-yr. periodicity in springtime surface temperatures for more than 100 yr. What might be the significance of such a periodicity? If the quasi-biennial oscillation were of 27-mo. period, then a temperature or ozone maximum in, say, March of an even year would occur again in March of an even year after 18 yr. Thus, there is indirect evidence that the quasi-biennial oscillation exerts considerable influence in polar and (more recently) temperate latitudes.

Brier [9] has emphasized the existence of a 27-mo. period in lunar-induced tidal oscillations, and in an ad-

dendum (fig. 2 of [10]) has presented a graph of the amplitude of the solar semidiurnal tide at Batavia, Java (6°S.). This graph is in phase with the Arosa total ozone trace (fig. 5), but, of course, this may be pure coincidence. Nevertheless, on the basis of the preliminary results presented herein, it appears worthwhile to carry out, on at least a hemispheric scale, more comprehensive studies of the differences in surface temperature, pressure, and pressure gradient between even years and odd years, and to compare the findings therefrom with tidal phenomena.

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